

PROJECT ADMINISTRATION DATA SHEET



ORIGINAL



REVISION NO. _____

Project No. E-20-677 (R6016-0A0)GTRC/~~STIA~~DATE 8 / 26 / 85Project Director: Daniel W. HalpinSchool/Lab XXXX

CE

Sponsor: National Science FoundationType Agreement: Grant INT-8500378Award Period: From 9/1/85 To 2/28/87 * (Performance) 5/31/87 (Reports)Sponsor Amount: This ChangeTotal to DateEstimated: \$ _____ \$ 7,786Funded: \$ _____ \$ 7,786

Cost Sharing Amount: \$ _____ Cost Sharing No: _____

Title: U.S.-Switzerland Cooperative Research: Study of Swiss Construction Technologies and Their Impact on the Production of Various Construction Processes

ADMINISTRATIVE DATA

OCA Contact John B. Schonk x4820

1) Sponsor Technical Contact:

2) Sponsor Admin/Contractual Matters:

Henryk M. UznanskiHerbert D. WolffNational Science FoundationNational Science FoundationSTIA/INTDGC/STIAWashington, DC 20550Washington, DC 20550202/357-7554202/357-9602Defense Priority Rating: N/AMilitary Security Classification: N/A(or) Company/Industrial Proprietary: N/A

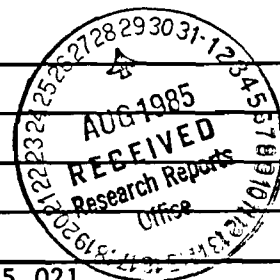
RESTRICTIONS

See Attached NSF Supplemental Information Sheet for Additional Requirements.

Travel: Foreign travel must have prior approval - Contact OCA in each case. Domestic travel requires sponsor approval where total will exceed greater of \$500 or 125% of approved proposal budget category.

Equipment: Title vests with GIT

COMMENTS:

*Includes 6 month unfunded flexibility period.No funds may be expended after 2/28/87.

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SPONSORED PROJECT TERMINATION/CLOSEOUT SHEET

Date4-15-87

Project No.E-20-677School/ LabXXXCE

Includes Subproject No.(s)N/A

Project Director(s)Daniel W. HalpinGTRC / GTR

SponsorNational Science Foundation

TitleU.S. -Switzerland Cooperative Research: Study of Swiss Construction Technologies and Their Impact on the Production of Various Construction Processes

Effective Completion Date: 2/28/87 (Performance) 5/31/87 (Reports)

Grant/Contract Closeout Actions Remaining:

- ☒ None
- ☐ Final Invoice or Final Fiscal Report
- ☐ Closing Documents
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- ☐ Govt. Property Inventory & Related Certificate
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PART I—PROJECT IDENTIFICATION INFORMATION

1. Institution and Address Georgia Tech Research Corporation Georgia Institute of Technology Atlanta, GA 30332	2. NSF Program International Programs	3. NSF Award Number INT-8500378
	4. Award Period From 3/15/85 To 2/28/87	5. Cumulative Award Amount \$7,786
6. Project Title U.S. - Switzerland Cooperative Research-Study of Swiss Construction Technologies and their Impact on Construction Productivity		

PART II—SUMMARY OF COMPLETED PROJECT (FOR PUBLIC USE)

The study found that the Swiss achieve high levels of productivity during the construction period by using an approach which integrates the design and construction of major projects. This approach forces the engineer to consider the method of construction during the design period. Considerable engineering is done during the construction period to improve the methodology used to realize the project. The U.S. industry can benefit from a better understanding of the method of contracting and approach to construction engineering.

PART III—TECHNICAL INFORMATION (FOR PROGRAM MANAGEMENT USES)

1. ITEM (Check appropriate blocks)	NONE	ATTACHED	PREVIOUSLY FURNISHED	TO BE FURNISHED SEPARATELY TO PROGRAM	
				Check (✓)	Approx. Date
a. Abstracts of Theses	X				
b. Publication Citations		X			
c. Data on Scientific Collaborators	X				
d. Information on Inventions	X				
e. Technical Description of Project and Results		X			
f. Other (specify)					
2. Principal Investigator/Project Director Name (Typed) DANIEL W. HALPIN			3. Signature 		4. Date 30 March 87

PART IV - SUMMARY DATA ON PROJECT PERSONNEL

NSF Division _____

The data requested below will be used to develop a statistical profile on the personnel supported through NSF grants. The information on this part is solicited under the authority of the National Science Foundation Act of 1950, as amended. All information provided will be treated as confidential and will be safeguarded in accordance with the provisions of the Privacy Act of 1974. NSF requires that a single copy of this part be submitted with each Final Project Report (NSF Form 98A); however, submission of the requested information is not mandatory and is not a precondition of future awards. If you do not wish to submit this information, please check this box ☐

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Asian or Pacific Islander	0	0										
Black, Not of Hispanic Origin	0	0										
Hispanic	0	0										
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CONSTRUCTION EDUCATION AND RESEARCH IN CENTRAL EUROPE

By Daniel W. Halpin,¹ Boyd C. Paulson, Jr.,²

Adolf Schub³ and Jack H. Willenbrock⁴

Abstract. Construction engineering and management education in Central Europe, and its relationship to practice in the construction industry, have concepts that could benefit their counterparts in the United States. This paper first describes the system of education in Central European technical universities, then reviews curriculums in four cases. University research practices are also examined and compared to U.S. counterparts, as is the role of academics in industry. While there are many similarities in the two systems, there is more technical content in European degree programs, but at the expense of liberal arts courses. They have more decentralized autonomy in budgeting and staffing, with larger staff sizes to support comparable numbers of faculty and students; but they have lower capital equipment budgets. Finally, characteristics of the Central European construction industry that support research and innovation are examined. These include top management's greater interest in technology and innovation; a comparative lack of the legal liability problems; a bid evaluation system which encourages contractors to submit design alternatives; in-house contractor research laboratories; and a more cooperative contract administration climate.

Introduction and Overview

In recent decades, Central European contractors (Austrian, Swiss, West German) have moved to the forefront of technological advancement, innovation and productivity in many types of construction. Their bridge designs, tower cranes, concrete technologies and tunneling methods have become increasingly common in the American marketplace. In contrast, American construction, the undisputed world leader until two decades ago, appears at times to have suffered

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Acknowledgements

Various organizations provided financial support that enabled the authors to travel and study in Europe and the United States to better understand their respective construction industries. For Daniel Halpin, these include the Technical University of Munich, Georgia Institute of Technology, the Swiss Federal Institute of Technology, and the National Science Foundation under Grant INT-85-00378. Boyd Paulson's 1983 sabbatical was hosted by the Technical University of Munich, and was funded by the National Science Foundation under Grant INT-82-13913 and by a fellowship from the West Germany's Alexander Von Humboldt Foundation. Adolf Schub traveled to the United States on a Fulbright fellowship. Jack Willenbrock's sabbatical in West Germany was hosted by the Technical University of Munich. The support of all these organizations is gratefully acknowledged.

Appendix. - References

1. Halpin, Daniel W., *A Study of Swiss Construction Technologies and their Impact on Construction Production*, Final Report for National Science Foundation Grant INT-85-00378, February 1987.
2. Paulson, Boyd C., Jr., *A Study of the Role of Education and Research in Technological Advancement and Innovation in the West German Construction Industry*, Final Report for National Science Foundation Grant INT-82-13913, Nov. 4, 1983.
3. Schub, Adolf, *Lehre und Forschung im Fachgebiet Baubetrieb an Technischen Hochschulen und Universitaeten im deutschsprachigen Raum (Bundesrepublik Deutschland, Oesterreich, Schweiz)*, Institut fuer Bauplanung und Baubetrieb, Swiss Federal Institute of Technology, Zurich, Switzerland, September 1984.
4. Willenbrock, J. H., and Schub, A., *A Comparative Analysis of Construction-Related Educational Programs at Colleges and Universities in the United States, Germany, Switzerland, and Austria: Phase I Report: Construction Related Programs in the United States*, Technical University of Munich, August 1980.



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January 28, 1987
File No: 3297-4-CO.H

Prof. Daniel W. Haplin
A.J. Clark Prof. & Director,
Construction Engrg. & Mgmt. Program
The University of Maryland
College of Engrg.
Dept. of Civil Engineering
College Park, MD 20742

Subject: Construction Education and Research in Center Europe

By: Haplin/Paulson, Jr./Schub/Willenbrock

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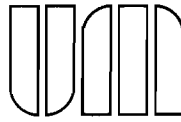
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March 4, 1987

MEMORANDUM

TO: Henryk M. Usznanski
Division of International Programs
National Science Foundation

FROM: Daniel W. Halpin, Clark Chair Professor

SUBJECT: Final Progress Report

1. Name of Institution: Georgia Institute of Technology
2. Name of Principal Investigator: Daniel W. Halpin
3. Grant No. INT-8500378
4. Starting Date: 15 March 1985
5. Completion Date: 28 February 1987
6. Grant Title: U.S. - Switzerland Cooperative Research-Study
of Swiss Construction Technologies and Their
Impact on Construction Productivity
7. Summary: The study found that the Swiss achieve high levels
of productivity during the construction period by
using an approach which intergrates the design and
construction of major projects. This approach
forces the engineer to consider the method of
construction during the design period.
considerable engineering is done during the
construction period to improve the methodology used
to realize the project. The U.S. industry can
benefit from a better understanding of the method
of contracting and approach to construction
engineering.

DWH/te

FINAL REPORT

U. S. - SWITZERLAND COOPERATIVE RESEARCH
STUDY OF SWISS CONSTRUCTION TECHNOLOGIES

AND

THEIR IMPACT ON CONSTRUCTION PRODUCTIVITY

Submitted by

DANIEL W. HALPIN

to

NATIONAL SCIENCE FOUNDATION

under

NSF GRANT NO. INT-8500278

FEBRUARY 1987

Swiss Construction Technologies
and
Their Impact on Construction Productivity

Introduction

Switzerland is a European country approximately the size of the northern third of Georgia. It can be divided into three areas topographically (1) the low mountains of the Jura (2) the midlands and (3) mountainous terrain of the Alps. The nature of the terrain has confronted Swiss engineers with unique construction problems. Despite its relatively small land area of which a large percent is virtually uninhabitable, its population is almost twice that of Georgia. Therefore, construction is characterized by a high density of population in the urban areas and communications routes between urban areas which must cross difficult terrain. Due to the high relief topography, large lakes are also characteristic of the country and water related projects pose an engineering challenge.

A relatively high percent of the GNP is dedicated to the construction sector and the per capita expenditure in the construction area is roughly 2.5 times that spent in the U.S. The nature of the construction environment in Switzerland has led to unique construction solutions. Particularly, in the areas of tunneling, bridging and surveying the Swiss have achieved a position as world leaders.

The Swiss have been able to compete very effectively in the world engineering and construction markets in a wide range of projects notwithstanding their relatively small size. In addition to bridging and tunneling, Swiss firms enjoy a very strong position in the areas of hydro-power and water resources development as well as a wide range of subsurface construction techniques. As a complement to the interest in bridging, the concrete industry in Switzerland is very sophisticated. The most modern methods of prestressing, post-tensioning, and pre-casting are commonly used in building and engineering structures.

Materials science has supported advanced construction techniques. Products to control deterioration of the prestressing and post-tensioning elements as well as grouts for soil stabilization and control of rock fracture in tunnels are examples of the advancing materials developments in Switzerland. Special methodologies such as shotcreting, rock drilling, frozen ground control, and slurry construction techniques are very advanced and widely used. In effect, the maxim of "necessity is the mother of invention" is very relevant in Switzerland. The engineering challenge of the construction environment has led to elegant solutions.

The Swiss are at or near the state-of-the-art in the following physical systems technologies with the competition as listed:

<u>TECHNOLOGY</u>	<u>COMPETITORS</u>
Pile Foundations (by jetting)	Germany, France, Italy, England
Tie back Walls	Germany, France, Italy, and Austria
Tunneling Drill and Blast	Austria, Italy, France, Spain, Norway Sweden, Finland, Japan
Tunneling Boring Machine (TBM)	Austria
Mixed Face Tunneling	Germany, France, Italy, England, Japan
Hydro Power Facilities	The industrialized middle Europeans and the Scandinavians
Nuclear Power	Germany, France, England and Sweden
Bridging	Germany, France, Italy, Austria, Japan
Waste Water Processing	Germany, England, Sweden, Japan
Railroads	Germany, France, Japan
Buildings	Germany, Sweden, France
Building Control	Germany, Denmark, Sweden

These observations are based on interviews with Swiss construction experts.

Interplay Between Engineering and Construction

Swiss contracting procedure encourages a design competition on most major projects. The designer must not only present his credentials and qualifications, but must also submit sufficient design material so that his proposed design can be evaluated. This evaluation is typically based on (1) structural concept (2) safety, (3) cost of construction, and (4) aesthetics. The importance of each of these factors is based on the type of project and other considerations. This notwithstanding, the proposed designs must address both purely engineering considerations and the construction methodology. This is why bridges in Switzerland have become famous for the integration of design and construction engineering to achieve cost effectiveness and beauty of structure.

Good projects are based upon a balanced integration of engineering functionality and quality with cost efficiency in the construction phase. Engineering which does not take the problems of construction into consideration may lead to minimal improvements in functionality and durability of a project at an exorbitant increase in construction costs. This occurs due to lack of appreciation of the field erection problems on the part of the designer. The Swiss emphasize design which attempts to optimize field construction efficiency and enhance construction productivity.

On projects where a design-build approach is to be used, the communication between designer and constructor is theoretically enhanced since they are on the same "team." This approach is common in Switzerland.

The design competition approach referred to above is a contracting method which makes the designer more responsive to the problems of the constructor in realizing the project in the field. The famous Swiss bridge designer, Christian Menn, in a recent speech to the Transportation Research Board, characterized the Swiss design competition in terms of the evaluation criterion. Normally, 5 to 7 design offices are selected to compete for a major bridge design. The designs submitted must include:

- (1) Conceptual Design of the Structural System
- (2) Calculation of all of the critical cross-sections
- (3) Proposed Construction techniques

The fact that the designer must submit the proposed scheme of construction for evaluation, forces the designer to think beyond the pure design stage to the construction of the project in the field. For this reason, Swiss designers are much more innovative in design (in order to win the contract) and much more innovative in developing construction methods (which will implement their designs) than are their American colleagues.

The evaluation of the submitted designs is based upon:

- (1) Safety
- (2) Servicability
- (3) Economy (i.e. Cost)
- (4) Aesthetics

All design submittals are costed out by an independent estimating firm so that the same cost factors are applied to all bids. Then the evaluation board selects the design to be constructed. According to Menn, the low cost solution is not normally the selected concept. Rather, the design with the best balance between servicability and cost is normally selected.

The concept of servicability includes the factors of:

- (1) Durability
- (2) Functionality
- (3) Acceptable appearance

In effect, the deciding factor is the balance between performance, quality, and cost (and not cost alone).

Two points are important. First, designs in the U.S due to our contractual approach may overemphasize the lowest price at the expense of quality and durability. Secondly, the American designer is not greatly interested in the constructability of his design or the construction cost implications of his design decisions. Many decisions are made to limit liability and maintain a conservative design.

This is due in large part to the U.S. contracting system which breaks the realization of a project into design and construction phases. This produces an adversary relationship between designer and constructor and acts as a barrier to cooperation and the integration of design and construction approaches to maximize the constructability advantage.

The Swiss are used to integrating the two activities and optimizing the advantages of engineering and construction to achieve servicable and cost effective projects.

Some of the advantages that accrue through this integrated approach as outlined by O'Connor in a recent article in the Journal of Construction Engineering and Management, ASCE are:

- "(1) The likelihood of delays may be decreased most effectively by increasing engineering information availability and understandability.
- (2) The amount of required construction manpower may be most effectively decreased by simplifying the design, combining design elements, and seeking optimal design-oriented construction techniques such as optimal construction systems, modularization and improved design details.
- (3) Construction activity durations may also be most effectively decreased by seeking optimal design-originated construction techniques." *

Type of Technologies

Technologies can be characterized as:

- (1) Data Intensive Technologies
- (2) Physical Systems Technologies

Engineering, construction management, and to a somewhat lesser extent architectural design are data intensive activities. Large volumes of data are required to conceptualize, determine feasibility, design and manage the construction of projects of any significant size.

Physical systems technologies pertain to the methods and materials which are utilized to actually construct a project. Both methods and materials can influence the nature of the design and the quality of the construction. In many cases, more sophisticated methods and materials insure a more durable product and thus provide a longer service life. Sophisticated physical systems are also attractive from the aesthetic and prestige point of view.

Physical Construction Systems

Buildings, industrial plants and similar facilities are the end products of any construction project. These units represent systems made up of physical elements (e.g. foundations, vertical structure) which can be considered systems. Physical systems will be considered to be methods and materials which represent technologies where advantage or disadvantage can exist among competitors.

* See O'Connor, James T., "Impact of Constructability Improvement," Journal of Construction Engineering and Management, ASCE, December 1985, pp. 404-410

The industrial revolution, which brought the idea of mass production, sought to optimize the efficiency of resource utilization. The corner stone of mass production is repetitiveness of the work to be performed. This is based on the standardization of the product to be created. Standardization and modularization are historically well known concepts for construction materials (e.g., brick sizes) but, until recently, have been less successfully applied at the level of construction processes.

While other industries have successfully standardized products, product parts, and production methods, this concept has not filtered through to the construction industry. Recently, successes on large projects have proven that repetitiveness is the basis for cost effective construction which also yields high quality. The use of repetitive processes based on incremental construction techniques is central to the Swiss construction approach. It yields high productivity with a relatively small labor force. This is important in a country with a limited labor force and challenging construction problems.

Standardization and Modularization

In order to achieve cost and time saving standardization, the architectural/engineering design and the construction design have to be interrelated to be successful. In Switzerland, many projects show evidence that construction materials, construction methods and design have been integrated into a systems approach in which the interaction among these components is optimized.

In Switzerland, the objective of standardization is repetitive production processes at all levels of construction. The advantages of economies of scale can be used in design (e.g. segmental bridges), construction (e.g. in formwork), or in material processing (e.g. batching facilities). This has led to greater use of modularization and off-site prefabrication. Modules of the plant can be prefabricated and preassembled offsite. Similar trends are recognizable in residential housing, bridge construction, and other applications which involve both design and construction in a close working relationship.

Advanced Fabrication Concepts

Generally, four fabrication concepts are identifiable.

- A. Total construction on site
- B. On-site prefabrication in mobile plants
- C. Off-site fabrication of major components with on-site assembly and erection
- D. Off-site fabrication of major modules with erection and connection on site

On-Site Construction

Off-Site Construction

.....

A

B

C

D

Within the past decade, more and more fabrication processes have begun to utilize format "D" allowing modules to be produced in off site facilities and then shipped and assembled on site. The main obstacle to this approach is the handling of the bigger and bigger modules constrained by the critical tasks of horizontal transport and lifting.

Most advanced techniques in all four different concepts (A to D) try to apply repetitiveness with as much flexibility as possible. Simplicity and quality are the main thrusts.

F O R M A T A

In this format, fabrication is confined to the job site. Improvements in productivity are dependent upon the use of new materials for higher quality and flexibility, "smarter" tools and equipment to speed up production, and instant supporting elements (e.g. flying forms and scaffolds). In pipeline construction, for example, new techniques speed up the welding process and bring reliable quality which is checked by radiography in real time. The slipform technique for highrise construction is based upon repetition. The same is true of concrete and asphalt spreaders for highway and airfield runway construction. Sensors and lasers are used to guide and control these machines.

FORMAT B

Format B utilizes the advantage of mechanized plants located on the job site. This may be in the form of a batch plant, a fabrication shop, or similar facility. One example is in bridge construction where the bridge is preassembled over one abutment and then launched over the support bents (pushed out from the bank as a single unit). The prefabrication of tunnel liners on site and the prefabrication of pipe spools in a fabrication shop are other examples. Transportation can limit the use of very large modules where it is not cost effective to move large units. In such cases, on-site prefabrication can be used.

Erection on site can become very critical, since the economies of scale will favor bigger elements. Special lifting techniques which require computer controlled sensors for measuring of forces and distances have already been developed in Germany (see Dr.-Ing. Ali Shahabadi, Sectional Method of Construction, Betonwerk + Fertigteil-Technik, June 1985).

FORMAT C

While wood and steel construction were probably the first to apply this concept, concrete has become extremely economical through the utilization of precast elements. Prefabricated trusses and girders in steel and wood (laminated) have been transported to the construction site and assembled in place (e.g. highrise steel construction) or assembled and then lifted as structural components. Bridge construction was one of the first to use off-site prefabrication (casting) for bridge superstructure elements which were then lifted into place at the site. The trend is clearly towards using bigger elements with higher concrete quality and heavier lifts. European precasters clearly have gained an advantage over the U.S. improving the flexibility of their formwork, the decorative aspects of facade panels and prestressed hollowcore concrete floor slabs, as well as the development of more efficient pouring and vibrating techniques.

FORMAT D

The concept of bringing large structural modules to the site developed as matter of necessity. Off-shore drilling for oil requires platforms which are sturdy enough to survive the harsh environment of heavy seas. The method which proved most efficient was construction of the platforms with pile legs in dry docks and then floating them to the drilling location for final installation. A 19,000 ton 255 by 243 ft. steel deck for the North Sea was fitted out with all required equipment before barge mounted cranes lifted it onto its supports (ENR 16 August 1984). The capability of floating heavy loads clearly triggered the idea of using this approach for other applications. For the Jubail project in Saudi Arabia, "plug-in" plant modules were floated from Japan to Jubail. In Japan, a 1300 ton prefabricated bridge tower has been floated and installed by a 3,000 ton floating crane.

Application of Swiss Technologies

In order to illustrate the application of Swiss construction methods and technologies, several projects will be discussed. One involves the construction of an open spandrel arch bridge in one of the very deep alpine valleys of the Italian area of Switzerland. The second project is in the middle of Zurich and involves the rehabilitation of one of the main bridges over the Limmat River using a unique replacement technique discussed. These two projects have common technological threads which are characteristic of the Swiss and in a broad sense the European approach to construction. They all emphasize the use of incremental repetitive building methods which simplify the construction approach and reduce the number of labor resources required to complete the job. This leads to a controlled and methodical approach which minimizes departure from the original plan, allows the consideration of problems in a controlled environment, and supports learning curve improvements on the part of the work force.

Arch Bridge Construction in the Val Crotta

The Valle di Muggio in the southern part of Switzerland is one of the most popular areas of the country for hikers and tourists. In order to accomodate the increasing automobile traffic in the area, the decision was made to replace a small single lane bridge over one of the neighboring valleys, the Val Crotta, with a modern arch bridge. The Engineering Construction office of the Canton of Tessin commissioned the design of a new replacement bridge.

The new bridge is 145 meters long with a center arch of 92 meters. The approach spans are 9.5 and 14.5 meters on the Bruzella side and 15.5 and 13.5 meters on the Cabbio side. The deck section carrying the roadway is of a slab construction supported by two large girders.

The substructure consists of two parallel arches each with a width of 1 meter. The depth of each arch varies from 1.3 to 1.8 meters. The arch support on the Bruzella side is 2.1 meters lower than on the Cabbio side. The two archs are 2.2 meter apart and cross bracing at the crown is 80 cm deep while the cross connectors at the arch supports are 160 cm deep.

The roadway is approximately 70 meters above the lowest point of the Val Crotta. Since the use of falsework to support the casting of the arches would have been prohibitively expensive, the design firm of Brenni-Dazio provided for an alternative to conventional support systems. Based on the specifications of the engineering design, the firm STAHLBAU AG in cooperation with the Engineering Office of Aschwanden and Speck offered a solution using a cable supported jump forming system.

Cable Supported Forming Systems for Arch Bridge Construction

When inclined cable support systems are considered, it is normally in connection with the support of permanent bridge structures with spans in excess of 200 meters. The suspension bridge across the Rhine River in Cologne is a well known example of an inclined cable supported structure. The new Sunshine State Parkway Bridge connecting St. Petersburg and

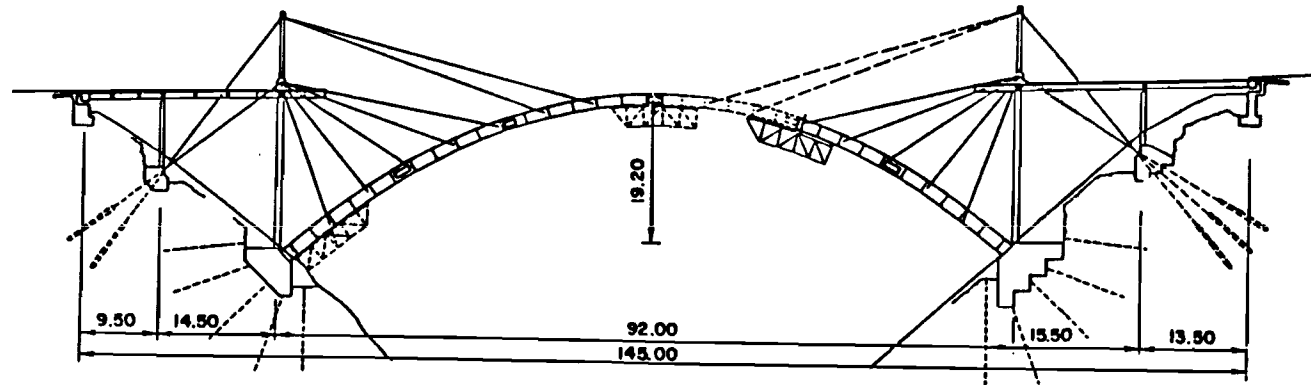


Figure 1 : Schematic of Inclined Cable Construction Procedure

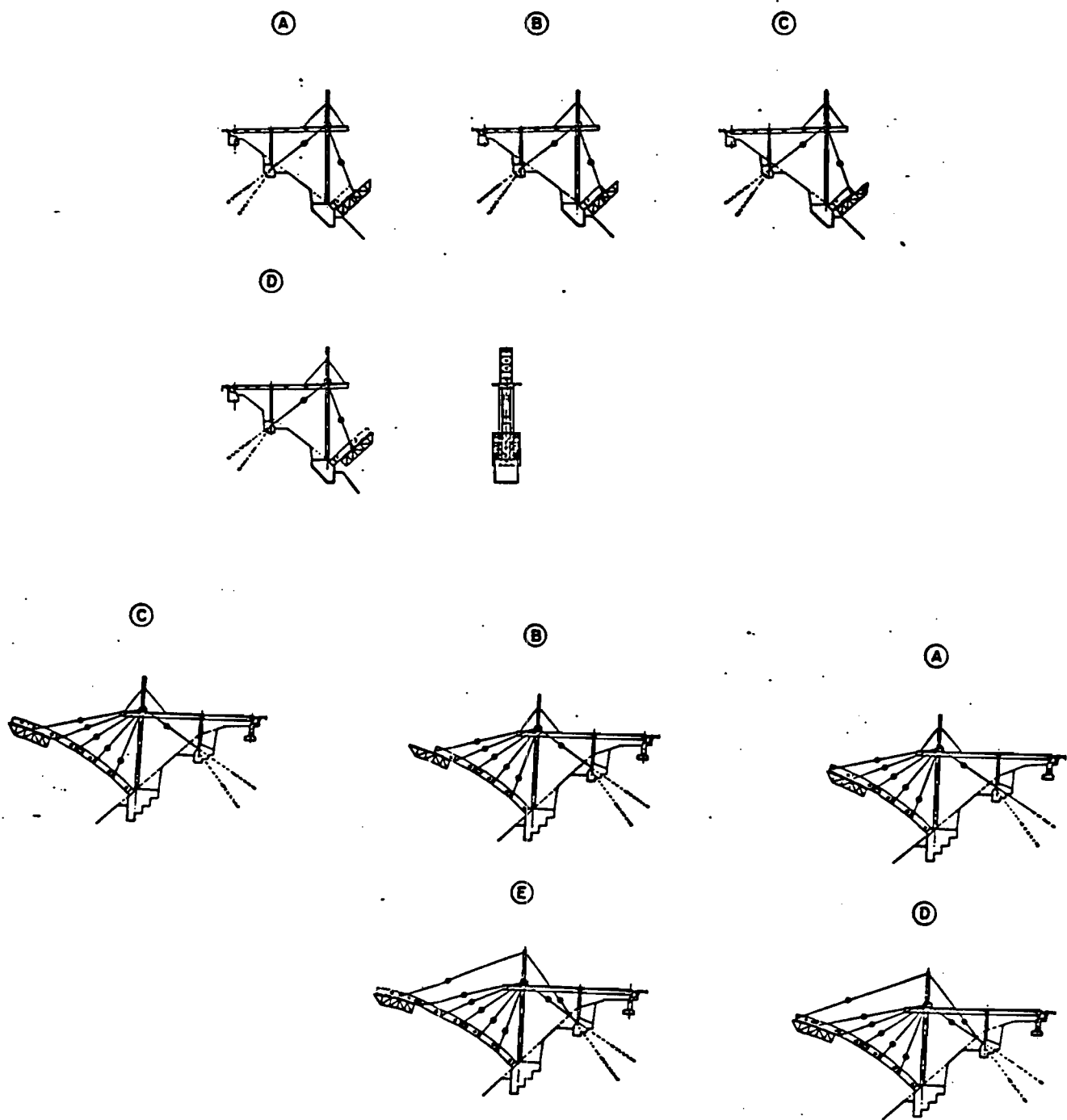


Figure 2: Jump Forming and Cable Support Sequence

Bradenton Florida is also an example of this method of support. This notwithstanding, a large number of smaller structures have been built using this technique as a permanent or temporary support system.

Figure 1 shows the way in which the inclined cable approach was used to cast in place the arch of the Val Crotta bridge. This is an application of Format A type construction. First pylons were constructed atop the approach ramps on each side of the valley high enough to support cables supporting the forming and (subsequently) the cast in place arch segments. As can be seen from the figure, 7 cables were supported from each pylon. 8 segments are cast sequentially on each side. Starting at each arch support, the jump form is advanced to a new location and prepared for casting. The previous steps are repeated on each side until all segments have been cast and supported except the crown (key) segment. This segment is cast last and the structural integrity of the arch is realized. Once the crown segment has achieved sufficient strength, the inclined cable supports can be removed. The repetitive process at various locations of the jump form is shown in Figure 2

The bid price submitted for this work by STAHLBAU AG was approximately \$1,000,000. It is clear this is substantially less than the price required

had conventional falsework support been used. This incremental approach reduced significantly the number of labor hours required and the size of the crew required. The precision of the casting was insured by careful survey control throughout the casting process. As each segment was formed and cast, measurements were made to insure that the two half arches would mate properly at the center.

Using an extension of this approach, the Austrian firm Ilbau constructed an arch bridge over the Argens River in southern Bavaria. Two gigantic half arches were "prefabricated" in a vertical position on the arch supports using jump forming procedures to form them as curved columns. The position of the half arches was maintained as the forming sequence advanced to keep the form moving vertically. The precise curvature of the

half arches was maintained by lasers at the arch supports used to monitor the operation. Once casting was complete, the half arches were then lowered into place using a computer controlled cable support system until the full arch was formed. The final 32.3 meter arch supports a bridge 232.3 meters deep in length. (See Reference, "Arch Halves Fall, Making Pivotal Link in Germany," Endr. News-Record, 21 June, 1985)

The technological and contracting approaches used in both of these projects are characteristic of European and Swiss construction methods.

- (1) Incremental jump forming techniques were used to cast the arch.
- (2) Cables were used as support during the construction period (and to lower the half arches in the case of the Argens River bridge).
- (3) Close coordination based on a design-build team approach characterized the relationship between the designer and the construction force.

Rehabilitation of the Quai Bridge in Zurich

A unique solution was developed to replace the Quai Bridge over the Limmat River in Zurich using a cable system to shift the old bridge superstructure off of its supports and slide a new bridge into position. The Quai bridge was originally constructed about a 100 years ago at the point where the Limmat flows into Lake Zurich (Zurichsee). The question regarding whether to simply repair or replace the bridge was decided in a meeting of the City Council on 26 September 1982. Based on a proposal submitted by the joint venture of Fietz Leuthold and Schneider Stahl- und Kesselbau the decision was made to replace the bridge superstructure with one of similar design but 2 meters wider to accomodate a lane for bicycle traffic.

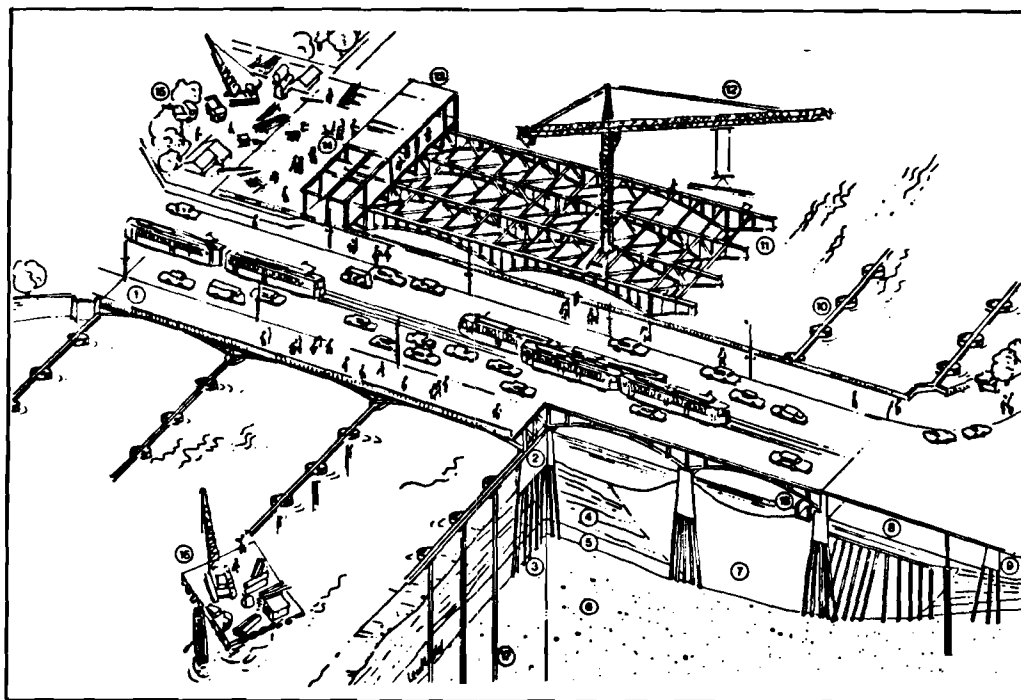


Fig. 3 General view of the work

- | | | | |
|----|--|----|--|
| 1 | old Quaibridge, built 1882-1884, widened in 1939 | 11 | four new welded steel girders Fe 510, erected on displacement tracks |
| 2 | pier, concrete with abutment of natural stone | 12 | tower crane |
| 3 | pier pile grating | 13 | removable falsework for the concrete slab |
| 4 | lakemarl | 14 | pouring section, length 12 m |
| 5 | mud | 15 | installation site |
| 6 | stratum of glacial period, foundation of the pile gratings | 16 | Floating pile driver |
| 7 | Slide of 1883 | 17 | piles of displacement track, quantity - 40, \varnothing - 1.22 m |
| 8 | Bellevue cavern | 18 | concrete trough for pedestrian underpass |
| 9 | old embankment | | |
| 10 | displacement track | | |

The proposal submitted by the contracting group was attractive since it minimized the period of time during which the bridge would be closed to traffic and maximized the productivity of the construction labor force. The technique is basically a Format B method in which the construction was prefabricated on the site and then installed in its permanent location. A relatively small labor force was able to work incrementally in preparing the new bridge for installation.

The Contracting Team's Proposal *

The new bridge spans - consisting of four new steel girders and a post-tensioned concrete slab poured on site were built on displacement tracks and temporary piles in the Limmat River. The traffic continued to use the old bridge during the time the new bridge was being constructed in a parallel position (see Figure 3). During this period, the existing bridge piers were prepared for the replacement. After completion of the new span in parallel position, it was pulled into its new position during the period of one weekend. The new span as it moved into position pushed the old span along the displacement tracks to a position on the lake side parallel to its original location. Following this displacement, the old span was dismantled and removed.

The procedure used consisted of the following steps:

1. A platform was built on the Limmat side of the existing bridge near the West abutment. Prefabricated slabs were constructed on previously driven piles. This platform was used as the access to the new bridge in its prefabrication location. The crane used on the new bridge construction used this access.
2. Next, the temporary piles for the displacement track were augered into the river bottom.
3. Simultaneously, the existing bridge piers and abutments were repaired with cement injections. Reinforcing tension and compression members were added on top and at the bottom of the piers.

* This and the following section are based directly on the paper "Renewal of the Old Quai Bridge in Zurich" by Robert Fechtig, published in IABSE Journal J-30/86 in May 1986.

4. At this point, the pile caps and the displacement tracks were installed on the up river side. The final position of the tracks was partially below the water.
5. The steel girders for the new bridge were placed in 10 major phases, with much of the work accomplished at night. The crane utilized a track which was extended as construction progressed.
6. When the first three span girder sections were placed and welded, a mobile casting bed was used to form and cast the first sections of the roadway slab. A section of 12 lineal meters in the direction of traffic took about one week to construct. 10 such pours were required for the entire bridge deck slab.
7. During this time, the piles and displacement track on the lakeside of the old bridge were installed.
8. At the time of the pier repair (3 above), the supports of the existing bridge girders were replaced by sliding bearings. This included extension of the displacement track to the area below the existing bridge.
9. Utility lines were installed beneath the new bridge deck slab.
10. The necessary reinforcing and force redistribution elements and equipment were installed. Some more temporary scaffolds and platforms were added.
11. The displacement of both the new and the existing bridge took place during one weekend according a carefully developed schedule. The new span literally pushed the old span out of the way.
12. After the displacement, the deck joints were set and the utilities were linked together. The bridge was now ready for service.
13. The old bridge and the support structures (e.g. displacement tracks) were dismantled and removed from the site.

Figure 4 below shows a cross section of the new bridge in its final position.

Displacement Procedure

The weight of the existing and the new bridge superstructures as a unit package was approximately 7800 tons. On the order of 100 tons of pull had to be developed in each displacement track. The rate of displacement was 2.5 mm/second or 25 cm for each step in the pull sequence. After each meter of displacement, extensive measurements were made to control the structure and identify variances from the plan. The results were compared to precalculated values of system response. All response values were available on a computer and immediately checked against field data. The piles were particularly sensitive since horizontal displacement of these supports was not acceptable.

The displacement sequence can be divided into three main phases:

1. The old bridge had to be mounted on slide supports in order to provide for sideward displacement. The slide supports were locked onto the displacement track until the start of the displacement. The old support contact areas were reworked to accommodate the sliding bearings. The existing bridge was temporarily supported by a system of hydraulic jacks that simulated the existing support conditions. This was all done under normal traffic.
2. Eight VSL-strand tension apparatus were used to pull the new bridge on cables into the planned position. The existing bridge was pushed ahead by the new one onto the lakeside displacement track. A special structure between the second and third main girders of the new bridge was designed to take the displacement force. (See Figure 5) The cables were affixed to anchorage points on the lakeside displacement track. Piles and contact points experienced only moderate horizontal stresses using this system.

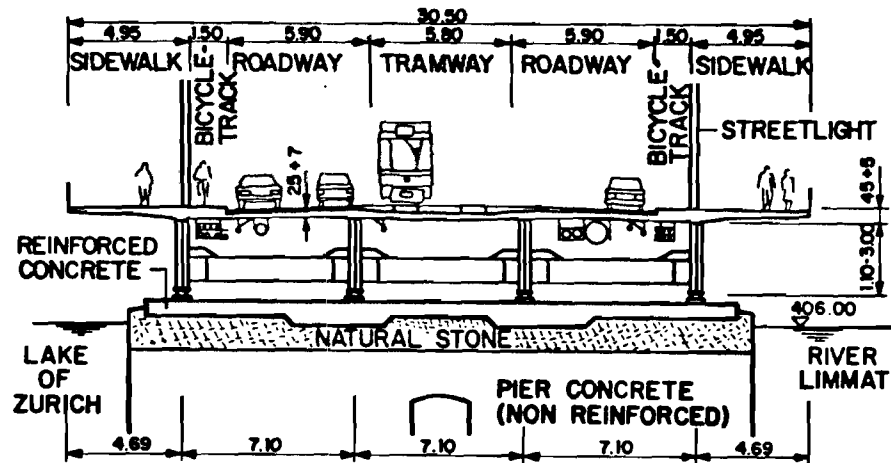


Fig. 4: Cross section of the new bridge with traffic areas

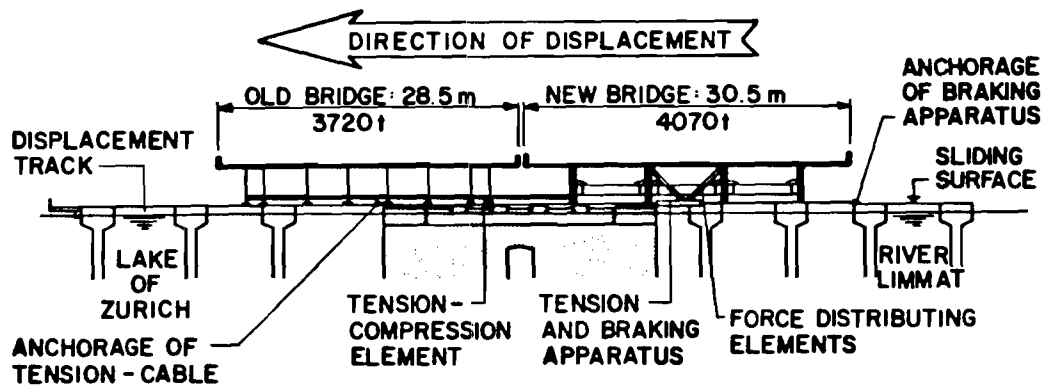


Fig. 5: Transverse section with displacement equipment

The sliding supports were chromed on the underside. They slipped on teflon coated neoprene cushions. This system provided for smooth load-transfer in the event of unevenness of the displacement track.

3. After completion of the displacement, the lower sliding part of the slidetrack was removed and replaced by lining plates of the same thickness.

The displacement tracks on the temporary piles were welded box girders. Over the piers, the track was 60 centimeter wide steel sheet. Concrete repair of the piers and abutments was accomplished using the "Colcrete" method to build up the compression members.

Subsurface Construction in Zurich

In connection with the expansion of the Zurich rail transit system, a large number of projects are in progress which demonstrate the variety of technologies the Swiss utilize in sub-surface construction. One of the most unique projects has to do with the use of ground freezing technology to construct the portion of the transit line which crosses beneath the Limmat River in the vicinity of the main train station. This work is divided into two contracts which use several techniques in addition to the ground freezing approach.

Access to the work is through two large shafts which are constructed as coffered structures on either side of the river. These are referred to as the Bahnhof Shaft and the Limmat Shaft. The portion of the job between the Bahnhof shaft and the left side of Figure 6 is being constructed using the slurry wall methodology to cast the side walls of the tunnel, the construction of the top or roof section of the tunnel at grade (casting from side wall to side wall) and then the excavation of material after the structural integrity of the walls and roof section has been achieved.

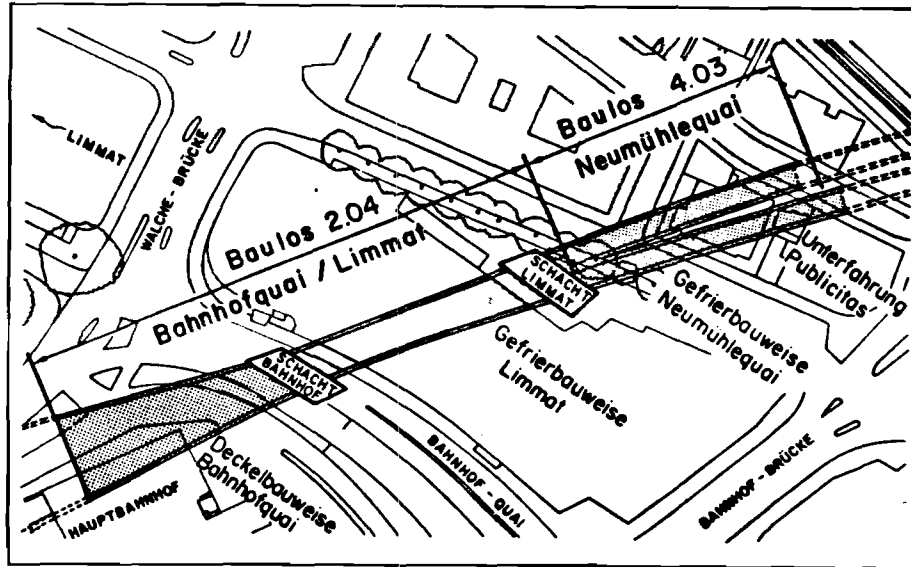
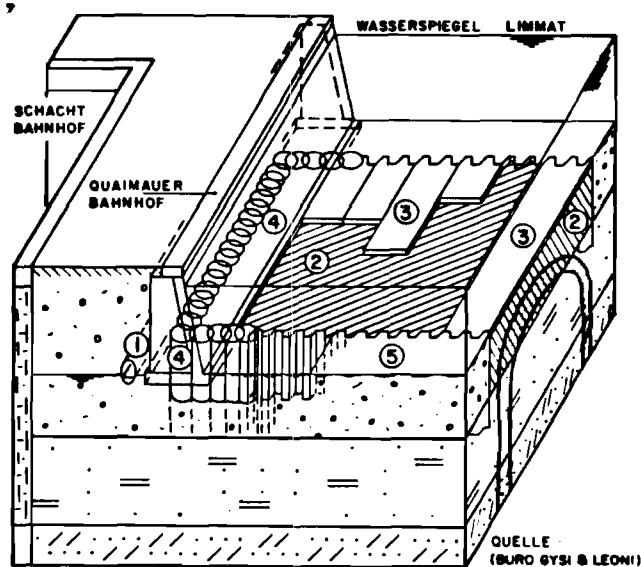


Figure 6: Site Plan with Location of Contract Package 2.04 & Contract Package 4.03



- | | |
|--|-----------------------------------|
| 1 - Drainage Pipe | [Symbol] - Sheet Pile Wall |
| 2 - Compacted River Bottom above Freeze Zone | [Symbol] - Frozen Zone |
| 3 - Insulation Blanket | [Symbol] - River Bottom Material |
| 4 - Secant Pile Wall | [Symbol] - Alluvial Lake Deposits |
| 5 - Retaining Structure | [Symbol] - Bed Rock |

Figure 7: Isometric Diagram of Construction Zone

The remainder of the tunnel will be constructed by mining the material away from the heading once ground control has been achieved using the ground freezing approach. This portion of the work includes that under the river as well as the approach tunnels beyond the Limmat Shaft. Working from this access (Limmat Shaft), three different tunneling methods will be used. In all cases, ground control here is achieved by ground freezing.

One of the major problems encountered in using the ground freezing approach under the river has been the proximity of the river bed to the top of the tunnel and the required ground control area. Since the cover between the frozen zone and the river bottom is only 2.5 to 3.5 meters, the river water acts to heat the areas of the refrigeration probes and causes holes or windows in the cross section of the frozen zone (See figure 7). In order to control this problem, a unique blanket of insulation material has been constructed and placed on the river bottom in the area of the crossing. This blanket is restrained using a cable mat. A special barge has been constructed to drop the blanket and restraining mat into position.

A schematic of the mining of the material in the area of the Limmat Shaft is shown in Figure 8.

Construction of the S-Bahn in the Ramistrasse

The routing of the transit line required subsurface construction beneath the historic buildings of the Ramistrasse near the area of the Swiss Federal Institute of Technology where Einstein studied physics. Again, a design construction competition was initiated to determine how best to secure the integrity of these buildings and efficiently construct this part of the line. This required the establishment of joint ventures between engineer offices and construction companies. A variety of proposals envisioning sophisticated underpinning methods based on retaining pile systems and slurry wall construction was submitted.

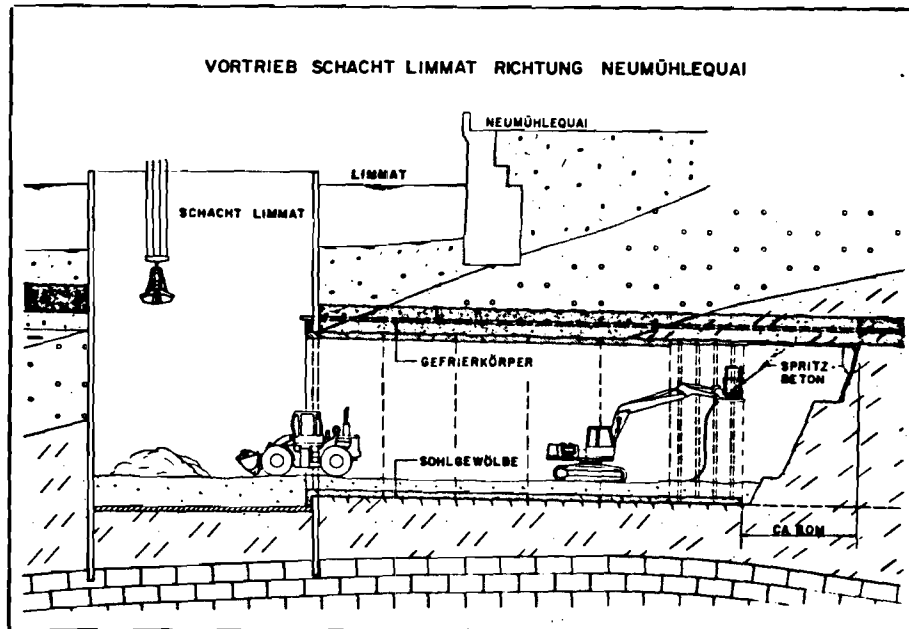


Figure 8: Schematic Diagram of Tunneling
Activity below the Frozen Zone
(Gefrier Körper)

Based on an initial screening, certain of the submitting groups were selected for further consideration. These groups were given 3 months to submit definitive design and construction proposals to include all preliminary design calculations and construction planning. Only very limited information regarding the foundation systems of the buildings in the area as well as the geology of the construction area was available.

The solution selected to accomplish the underpinning and construction of the tunnel section requires a two step approach. First the basement walls of the buildings are supported using "micro" piles. This work is accomplished in the basements of the existing buildings and the placement of pile supports was achieved within the height restrictions of the basement depth. That is, the integrity of the basement ceiling was maintained and acted to insure that the lateral bracing of the structure was not impaired. The micro piles support grade beams which are affixed to the existing walls using post tensioned rods. The micro piles consist of pipes roughly 24" in diameter installed in lengths of 2 to 3 meters to build the required length of 11 to 14 meters. The pipes are filled with cement. This is an innovative use of pile auguring technology together with post tensioning expertise.

Once this initial underpinning is accomplished, the micropiles are loaded to support the building structures and the area below the existing building support footers is excavated to build a large concrete frame structure which ultimately supports the buildings after excavation for the rail tunnel is completed. This large concrete frame structure is constructed in a way similar to the Milan tunneling method described above. The frame side walls are constructed using large precast concrete wall elements which are placed in a narrow trench in a fashion similar to that used in slurry wall construction. Large horizontal framing members connect

the two side walls and ultimately accept the load from the micro piles. During the construction of the side walls and the framing members, the load distribution to the micro piles is accomplished through the grade beams using a jack system designed to adjust the loading. As of March 1986, the system had controlled settlement to less than 1 mm as required by the specifications.

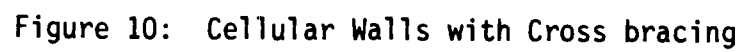
This is another example of the use of engineering expertise during the construction phase to handle an extremely difficult construction situation. The combination of advanced jack and load distribution systems together with pile installation in a very tight working area has led to an elegant solution to a difficult problem.

Figure 9 shows a cross section of the construction area during the initial underpinning using the micro piles. Figure 10 is a plan view of the location of the cellular side walls and the cross bracing members.

Implications of the Technology for Productivity

These projects demonstrate the innovative use of existing technologies to solve difficult construction problems. The design build nature of the Swiss approach to all major construction projects provides the basis for an elegant engineering solution to a wide variety of construction challenges.

One thing that is obvious is the different orientation to actual construction on the part of Swiss contractors versus those in the U.S. The Swiss contractor focuses much more effort in applying engineering to the construction process to come up with new and innovative ways of doing construction. The U.S. contractor, by contrast, tends to play the role of "labor broker" depending on the old methods which are not efficient but which the client will implicitly pay for in the bid price. This situation may be changing as international contractors enter the U.S. market with the design-build attitude which emphasizes new engineering solutions to traditional construction problems.



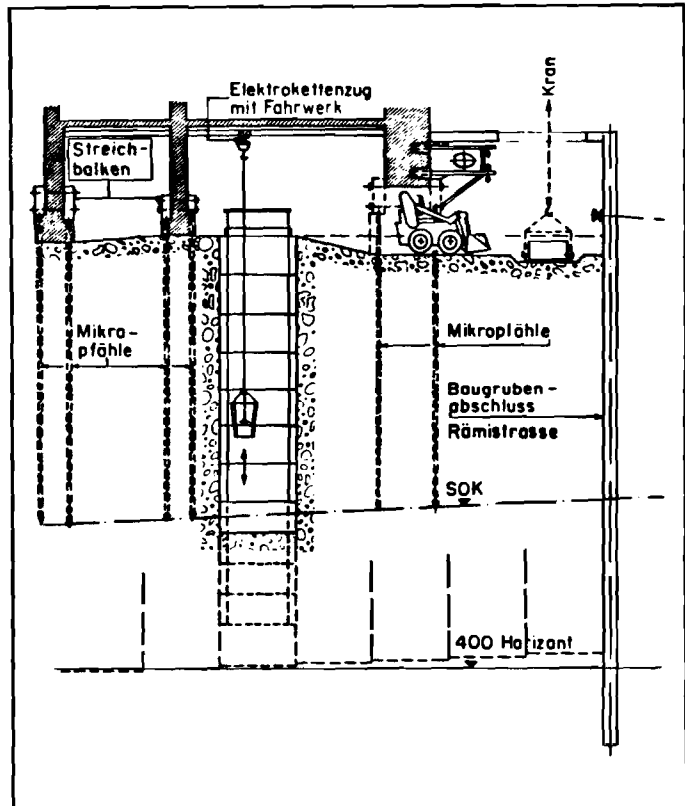
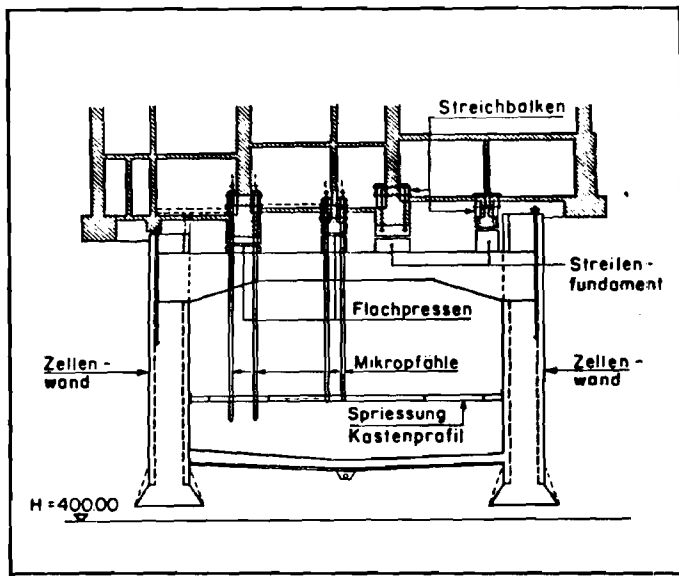


Figure 9: Cross Section of Construction Site during Initial Underpinning

This focus on more extensive engineering on the part of the constructor to develop innovative construction procedures in the field is a product of the educational system in Switzerland and other European countries. Courses in construction methods and technology are a large part of the training received by all Diplom Engineers. Courses in German speaking universities in "Verfahrenstechnik" emphasize the application of engineering principles to construction problems. Such courses are virtually non-existent in the U.S. curriculum.

Not only the design of the facility, but also the design of the construction process is of paramount importance. The design-build team cooperation facilitates the development of solutions which are engineered to facilitate construction and lead to improved productivity. This concept is beginning to gain some momentum in the U.S. under the general term of "Constructability." The basic contracting system, however, generally works at cross purposes to improved construction process development. The system supports an adversary relation between the designer and the constructor. This leads to inefficient costly designs being developed by the designer and costly methods being adopted on the part of constructors. Owners can help motivate an improved atmosphere in this area by adopting the design competition format used in Switzerland. This will force the designer to become more interested in engineering not only the permanent facility but also the process by which it is to be constructed.

The improved productivity that European countries are achieving is a by-product of this type of cooperation. Productivity improvement is achieved by ENGINEERING APPLIED TO CONSTRUCTION PROCESS DESIGN. The obvious spin-off from this approach is the development of numerous engineered products which are designed to facilitate the production process in construction. European and Japanese companies typically own numerous patents on construction techniques and methods. This is virtually unknown in the U.S. To a large degree this has resulted because the U.S. constructor is service oriented rather than product oriented. The Swiss construction industry as well as the international contracting community is definitely product oriented. Engineers are educated to design not only the project but the construction method are well.

The labor and machine productivity does not differ greatly among the industrialized countries. It is the engineering application of labor and machine resources that differs. The discipline of the Swiss worker is enhanced by the well planned application of engineering to the construction process. American engineers active in the architectural, engineering and construction areas seem to have lost an appreciation of this key point, and continue to engineer only the facility but not the construction process.

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